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LEVEL II

THE RELATIONSHIP BETWEEN AIR COMBAT MANEUVERING RANGE (ACMR) OUTPUT MEASURES AND INITIAL VISUAL ACQUISITION PERFORMANCE

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SUMMARY PAGE

THE PROBLEM

Initial visual acquisition of the adversary aircraft is a critically important task in air combat engagements. In order to assess capabilities for the performance of this task, it is necessary to identify the physical/flight variables which influence this performance.

FINDINGS

Measurements of 33 flight variables were recorded at the time of initial visual acquisition. Linear regression analysis was utilized to determine the relationship of each variable to acquisition range. Factor analysis revealed a clustering of the variables into four major factors: relative direction, target velocity, fighter velocity, and relative altitude. A multiple regression analysis was conducted, using these factors to predict acquisition range.

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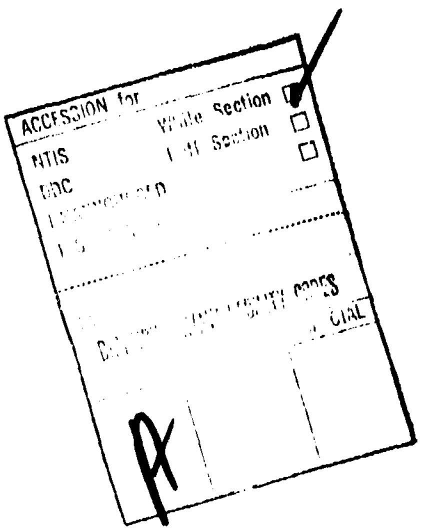

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INTRODUCTION

One of the more critical components of a successful air combat maneuvering (ACM) engagement is "seeing the adversary before he see you." The pilot who makes this initial visual acquisition has the distinct offensive advantage of initiating the engagement. This split-second head start on the problem can make the difference between making the "kill" and getting "killed." While there have been tremendous strides in the state-of-the-art in electronic sensor technology, the ground rules for air combat will most likely call for a "visual" prior to launching an air-to-air missile.

The present study represents the second phase of the Naval Aerospace Medical Research Laboratory (NAMRL) Air-to-Air Visual Target Acquisition Program. The first phase of this program involved the analysis of a randomly selected cross section of air combat engagements flown on the Air Combat Maneuvering Range (ACMR) over a six-month period. The data from that effort (1) revealed a considerable amount of mission specific variability and suggested the requirement for a more homogeneous set of ACM engagements in order to isolate those ACMR output measures which influence visual acquisition performance.

The present study involved the analysis of ACM engagements flown by a single Carrier Air Wing during a 10 day detachment to the ACMR and thus provided an opportunity to investigate a sample of ACM engagements flown under very similar climatic and mission oriented conditions.

The goal of these initial studies was to determine the relationship between the ACMR output measures currently available at the Display and debriefing Subsystems (DDS) of the ACMR and the initial visual acquisition performance of operational personnel. An understanding of these relationships will provide the basis for meeting the ultimate objective of development of a methodology for measurement and improvement of in-air visual acquisition capability of operational aircrews.

PROCEDURE

Each of the approximately 100 ACM engagements was recorded on one-inch magnetic tape for replay during debrief sessions. These tapes were initially screened for system status and general acceptability of the video and auditory signals. Data from 45 ACM engagements were found to be sufficiently free from degradation to qualify for study. Only "2 on 1" (two fighters vs one adversary) ACM engagements were considered due to potential confusion as to which target was being acquired during "2 on 2" engagements.

Each ACM engagement tape selected for inclusion in this study was replayed through the DDS display and auditory systems. All voice communications were monitored for an indication of an initial visual acquisition of the target aircraft (A-4) by the pilot of the fighter (F-4). A verbal report

("Tally Ho") signaled that the fighter pilot had visually acquired the target. At this signal the DDS tape drive was stopped, the exact time of acquisition verified, and all ACMR output measures associated with this event were recorded by means of a high-speed printer located in the DDS.

Linear regression analysis was utilized to determine the relationship between each ACMR output measure and visual acquisition range. The ACMR output measures found to have a significant relationship with the criterion were included in a multiple regression analysis.*

The complete set of 33 ACMR output measures was factor analyzed by the principal factors technique and rotated to the varimax criterion. The factor analysis was conducted in order to reduce the total set of ACMR measures to a smaller number of basic aerodynamic factors that would tend to be more stable and allow for a more complete understanding of the underlying constructs responsible for initial visual acquisition performance in an ACM environment. A factor score was computed for each aerodynamic factor on each ACM engagement. The relationship between the computed factors and initial visual acquisition range was then determined. Finally, a multiple regression analysis was conducted, using these factors to predict acquisition performance.

RESULTS

The range, arithmetic mean, standard deviation, and correlation with the criterion (range at initial visual acquisition) are listed for all fighter, target, and interaircraft parameters recorded on the ACMR in Tables I, II, and III, respectively. These tables represent, therefore, a comprehensive list of all relevant information available at the instant that a visual acquisition is reported. Those parameters having a significant ($p < .05$) relationship with visual acquisition are listed in Table IV. Of special interest is the surprising fact that the target's Y-axis direction (north vs. south) accounts for approximately 20 percent of the variance of acquisition performance. Another way of stating this relationship is to compare acquisition ranges for targets heading north against those heading toward the south. When a target's Y-axis velocity vector was positive (target going in a northerly direction), the mean acquisition range was 21,280.5 feet; when the Y-axis velocity vector was negative (target going in a southerly direction), the mean acquisition

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*Fourteen output measures demonstrated a significant relationship with the criterion. Only 11 of these measures were included in the subsequent multiple regression analysis. Two were excluded (fighter heading and direction of pitch) due to their redundancy with other measures. A third measure (antenna train angle) was excluded since it was based on a reduced number of observations ($N = 33$).

Table I

ACMR Fighter Parameters at Initial Visual

Acquisition (N = 45 Engagements)

ACMR Parameter	Range	Mean	S.D.	Validity ☆ Coefficient
Radar (contact vs no contact)	1 vs 0	.84	.37	-.260
True Air Speed (kts)	384 - 725	605.80	73.50	-.178
Angle of Attack (units)	4 - 10	6.50	1.49	-.004
Acceleration (G's)	0.6 - 3.6	1.70	0.86	-.103
Pitch Angle (degrees)	0 - 25	8.80	6.90	-.166
Pitch Direction (up vs down)	1 vs 0	.86	.35	-.282
Roll Angle (degrees)	0 - 71	25.40	23.20	.041
Roll Direction (right vs left)	1 vs 0	.34	.48	-.158
Heading (degrees)	46-303	143.30	70.10	-.303
X-Axis Velocity (ft/sec)	137-1063	860.70	207.30	-.089
X-Axis Direction (east vs west)	1 vs 0	.73	.45	.251
Y-Axis Velocity (ft/sec)	1-1054	346.20	253.90	.153
Y-Axis Direction (north vs south)	1 vs 0	.22	.42	-.046
Z-Axis Velocity (ft/sec)	0-415	131.30	106.60	-.099
Z-Axis Direction (climb vs dive)	1 vs 0	.82	.39	-.162

☆ Extent of relationship between parameter and range at time of visual acquisition.

Table II

ACMR Target Parameters at Initial Visual

Acquisition (N = 45 Engagements)

ACMR Parameter	Range	Mean	S.D.	Validity ☆ Coefficient
True Air Speed (kts)	248 - 555	479.90	65.20	.223
Angle of Attack (units)	6 - 23	9.10	3.90	-.306
Acceleration (G's)	0 - 3.7	1.50	0.87	-.229
Pitch Angle (degrees)	0 - 38	7.10	8.50	-.326
Pitch Direction (up vs down)	1 vs 0	.71	.46	.024
Roll Angle (degrees)	0 - 99	34.90	34.00	-.331
Roll Direction (right vs left)	1 vs 0	.58	.50	-.145
Heading (degrees)	48 - 342	240.00	91.80	.348
X-Axis Velocity (ft/sec)	200 - 941	718.00	201.50	.044
X-Axis Direction (east vs west)	1 vs 0	.24	.44	-.251
Y-Axis Velocity (ft/sec)	3 - 847	341.40	212.40	.163
Y-Axis Direction (north vs south)	1 vs 0	.76	.44	.445
Z-Axis Velocity (ft/sec)	0 - 373	83.90	95.00	-.272
Z-Axis Direction (climb vs dive)	1 vs 0	.56	.50	-.250
Perpendicular Velocity (ft/sec)⊕	4 - 751	320.70	211.70	.160

☆ Extent of relationship between parameter and range at time of visual acquisition.

⊕ Relative velocity vector of target perpendicular to fighter's longitudinal axis. This parameter is created by a translation of the ACMR X, Y, Z coordinate system to a fighter reference system (fighter position as the origin of the new coordinate system, and the new system was rotated to make one of its axes (Y) coincident with the fighter's longitudinal axis). This new velocity reference system combines both fighter and target velocity components into relative target velocity; i.e., as it appears to the pilot.

Table III

ACMR Interaircraft Parameters at

Initial Visual Acquisition

ACMR ACMR Parameter	Range	Mean	S.D.	Validity ☆ Coefficient
Altitude Separation (ft)	264-11,524	4253.80	3375.9	.256
Target (above vs below) ◇	1 vs 0	.62	.49	-.211
Antenna Train Angle ⊕	1 - 65	24.0	22.9	-.322
Range (ft)	2322-37943	18770.90	9411.2	- -
Closing Velocity (ft/sec)	1102-2092	1733.78	243.49	.046
Angle Off Tail ⊕	113 - 179	142.60	20.0	-.065

☆ Extent of relationship between parameter and range at time of visual acquisition.

⊕ Data on these ACMR output parameters was available on only 33 engagements vs the 45 engagements for all other parameters.

◇ Refers to position of target above or below fighter; i.e., relative Z-Axis position of target.

Table IV

ACMR Output Parameters Significantly ($p < .05$) Related to

Range at Initial Visual Acquisition

ACMR Parameter	N	Correlation with Range
Radar (contact vs no contact)	45	-.260
Pitch Direction (F)	45	-.282
Heading (F)	45	-.303
X-Axis Direction (F)	45	.251
Angle of Attack (T)	45	-.306
Pitch Angle (T)	45	-.326
Roll Angle (T)	45	-.331
Heading (T)	45	.348
X-Axis Direction (T)	45	-.261
Y-Axis Direction (T)	45	.445
Z-Axis Direction (T)	45	-.260
Z-Axis Velocity (T)	45	-.272
Altitude Separation	45	.256
Antenna Train Angle	33	-.322

(F) indicates that parameter applies to fighter.

(T) indicates that parameter applies to target.

range was 11,483.8 feet ($t = 3.26$, $p < .001$). This finding was also seen in the earlier study (1), where mean range for targets heading in a northerly direction was 16,739 feet while that for targets heading in a southerly direction was 10,110 feet.

Table V lists the contribution of selected ACMR output variables to criterion variance. The multiple correlation coefficient achieved by this analysis was .6637 ($p < .01$) which indicates that 44.05 percent of the criterion variance is explained by these ACMR output measures. Y-axis direction of the target, X-axis direction of the fighter, and the presence or absence of a radar contact were significant contributors.

Since the individual contribution of an output measure to the criterion variance is a function of the order of extraction when the measures are interrelated, the unique contribution of each of the 11 significant ACMR output measures was computed. The unique contribution of each significant ACMR output measure to the prediction of the criterion is listed on Table VI. By unique contribution is meant the extent to which adding a given variable increases the squared multiple correlation coefficient beyond that achieved by the remaining variables. As can be seen by inspection of this table, only the Y-axis direction of the target and the target's velocity component perpendicular to the fighter's heading make significant contributions to the multiple correlation coefficient after all the other variables have been accounted for. It must be noted, however, that the nonsignificance of a variable's unique contribution to criterion variance does not necessarily imply that it is not an important parameter. It only means that its contribution to criterion variance is redundant with other variables in the set.

The factor analysis of the 33 ACMR output parameters resulted in four significant factors. These four factors accounted for 53 percent of the total variance of the original 33 measures. The factor loadings (correlation between a variable and a factor) for the 33 ACMR output parameters on the four obtained factors are listed in Table VII. An inspection of this table indicates that these four factors describe the following aspects of the ACMR engagement:

Factor I - Relative Direction

Factor II - Target Velocity

Factor III - Fighter Velocity

Factor IV - Relative Altitude

The relationship between these four factors and range at initial visual acquisition is presented in Table VIII. As can be seen by this table the target velocity and relative direction factors have a significant relationship with initial visual acquisition performance.

Table V

Contribution of ACMR Output Parameters to Range

at Initial Visual Acquisition

Variable	R^2 Increment	F
Radar Contact	.0678	4.00*
X-Axis Direction (F)	.0799	4.71*
Angle of Attack (T)	.0656	3.87
Pitch Angle (T)	.0119	- -
Roll Angle (T)	.0066	- -
X-Axis Direction (T)	.0011	- -
Y-Axis Direction (T)	.0998	5.89**
Z-Axis Velocity (T)	.0006	- -
Z-Axis Direction (T)	.0277	1.63
Perpendicular Velocity (T)	.0542	3.20
Altitude Separation	.0253	1.49

(F) indicates that parameter applies to fighter.
(T) indicates that parameter applies to target.

R^2 = .4405

R = .6637

* $p < .05$
** $p < .01$

Table VI

Unique Contribution of ACMR Output Parameters to Prediction

of Range at Initial Acquisition

ACMR Parameter	Unique Contribution	Partial ☆ Correlation With Range
Radar Contact	.0222	.130
Altitude Separation	.0253	.139
X-Axis Direction (F)	.0028	.047
Angle of Attack (T)	.0003	.017
Pitch Angle (T)	.0027	.045
Roll Angle (T)	.0168	.113
X-Axis Direction (T)	.0006	.024
Y-Axis Direction (T)	.0681	.262*
Z-Axis Velocity (T)	.0018	.042
Z-Axis Direction (T)	.0105	.089
Perpendicular Velocity (T)	.0627	.250*

(F) indicates that parameter applies to fighter.

(T) indicates that parameter applies to target.

* ($p < .05$)

☆ This column represents the partial correlation of each parameter with the criterion with the ten remaining parameters partialed out.

Table VII

Factor Structure For ACMR Output Parameters

ACMR Parameter	Factor I	Factor II	Factor III	Factor IV
Radar Contact	.118	-.267	.262	.102
True Air Speed (F)	.127	-.103	.407	.005
Angle of Attack (F)	-.118	-.052	-.763	.278
Acceleration (F)	.010	-.101	-.545	.271
Pitch Angle (F)	-.130	-.042	-.245	.770
Pitch Direction	-.029	-.174	-.020	.571
Roll Angle (F)	-.268	-.156	-.699	-.161
Heading (F)	-.893	.030	-.208	.003
Heading (T)	.877	-.133	-.075	-.090
Yaw Angle (F)	-.018	-.186	.162	.098
Yaw Direction	-.081	.045	.217	-.127
Altitude Separation	.236	.004	.216	.607
Target High	-.085	-.101	-.018	.815
X-Axis Velocity (F)	.021	.018	.663	-.196
X-Axis Direction (F)	.896	-.020	.258	.020
Y-Axis Velocity (F)	.097	-.019	-.501	.352
Y-Axis Direction (F)	-.215	.001	.139	.029
Z-Axis Velocity (F)	-.104	-.017	-.191	.735
Z-Axis Direction (F)	.024	-.207	-.162	.484
Time of Engagement	.297	.041	.324	.283
Antenna Train Angle	.238	-.517	.095	.089
True Air Speed (T)	.122	.684	.206	-.143
Angle of Attack (T)	-.008	-.905	-.100	.074
Acceleration (T)	.038	-.697	-.104	-.047
Pitch Angle (T)	-.192	-.723	.099	.098
Roll Angle (T)	-.038	-.854	-.141	.140
X-Axis Velocity (T)	-.032	.475	.525	.031
X-Axis Direction (T)	-.964	-.004	-.144	.050
Y-Axis Velocity (T)	.108	.022	-.529	-.165
Y-Axis Direction (T)	.608	.136	.008	.041
Z-Axis Velocity (T)	-.254	-.595	.166	.011
Z-Axis Direction (T)	-.121	-.187	-.155	.087
Perpendicular Velocity (T)	-.069	-.056	-.506	-.035

(F) indicates that parameter applies to fighter.

(T) indicates that parameter applies to target.

Table VIII

Relevant ACMR Output Parameters Loading on

the Four Factors

Factor	Factor Loading	Relevant Parameters	Validity☆
(I) Relative Direction	-.984 .896 -.893 .877 .608	X-Axis Direction (T) X-Axis Direction (F) Heading (F) Heading (T) Y-Axis Direction (T)	.257*
(II) Target Velocity	-.905 -.854 -.723 -.697 .684 -.595	Angle of Attack (T) Roll Angle (T) Pitch Angle (T) Acceleration (T) True Air Speed (T) Z-Axis Velocity (T)	.360**
(III) Fighter Velocity	-.763 -.699 .663 -.545 .529 -.506	Angle of Attack (F) Roll Angle (F) X-Axis Velocity (F) Acceleration (F) Y-Axis Velocity (T) Perpendicular Velocity (T)	-.192
(IV) Relative Altitude	.815 .770 .735 .607 .571 .484	Target above Pitch Angle (F) Z-Axis Velocity (F) Altitude Separation Pitch Direction (F) Z-Axis Direction (F)	-.182

* $p < .05$

** $p < .01$

☆ Correlation of Factor with range at initial visual acquisition.

(F) indicates that parameter applies to fighter.

(T) indicates that parameter applies to target.

A multiple regression of the four factors on the criterion resulted in a multiple correlation coefficient of .515. The addition of three ACMR output parameters (Y-axis direction of the target, velocity vector of target perpendicular to the longitudinal axis of the fighter, and altitude separation) to these four factor scores increased the multiple correlation coefficient to .699. This indicates that seven aspects of an ACMR engagement account for almost 50 percent of the variance of initial visual acquisition. The individual contributions of these seven ACMR parameters to criterion variance and their individual regression weights are shown in Table IX. The first two ACMR output measures were included in the regression analysis in addition to the four factors because of their significant unique contribution to criterion variance (a contribution not shared by any of the other output parameters and thus not reflected in any of the four factors). The third output parameter - altitude separation (absolute value) - was included in this analysis due to the fact that it highest loading was on Factor IV and was in a reverse direction to this factor's validity coefficient, indicating that the component of altitude separation responsible for its loading on Factor IV was independent of that component responsible for the correlation between altitude separation and acquisition performance. The rather sizeable contribution of altitude separation to acquisition performance over and above that contributed by Factor IV strongly supports this interpretation.

Table IX

Contribution of ACMR Factors and Output Parameters to Initial Visual Acquisition

Parameter	R^2 Increment	Regression Weights	F
Factor I	.0544	.023	3.94*
Factor II	.1295	.304	9.37**
Factor III	.0479	-.147	3.47
Factor IV	.0336	-.389	2.43
Y-Axis Direction (T)	.0991	.336	7.17**
Perpendicular Velocity (T)	.0308	.225	2.23
Altitude Separation	.0935	.392	6.77**

R^2 = .4888

R = .6991

*p < .05

**p < .01

In order to explore more fully the role of altitude separation on initial visual acquisition range, the total set of 45 engagements was subdivided into two subsets: the 28 engagements where the target altitude was greater than that of the fighter (target above), and the 17 where the reverse situation existed (target below). For both subsets the relationship between altitude separation and acquisition range was independently computed. The resulting correlation coefficients were .576 ($p < .001$) and -.159 ($p > .05$) for target above and target below, respectively.

DISCUSSION

While the mean visual acquisition range of 18,771 feet found in this study is consistent with operational expectations, it is considerably lower than the range that would have been predicted from most laboratory data on human visual capability. The extreme variation in visual acquisition range in this study (2,322 to 37,943 feet) suggests that this process is extremely sensitive to operational variables. The results of this study indicate that this variance in visual acquisition performance is mainly a function of two constructs - a target velocity factor (Factor II) which explained a total of 12.95 percent of the acquisition variance and relative heading of the target (Factor I and Y-axis direction) which explained another 15.35 percent of this variance.

The rather surprising superiority in visual acquisition performance demonstrated for targets coming out of the south (almost 2 to 1) may be due to a difference in the background seen by pilots. Pilot comments on this phenomenon suggest that the background provided to pilots searching for targets coming out of the south is richer; i.e., more varied due to presence of mountainous terrain. This fact may reduce the "empty field myopia" effects by allowing the pilot more opportunity to fixate on objects at a distance from the cockpit. Another possible explanation for this difference in acquisition range may be that it is due to enhanced contrast ratios provided by targets against the mountainous background in the southern section of the ACMR.

The relationship between the perpendicular velocity component of the target (that component of target velocity which is perpendicular to the longitudinal axis of the fighter) and visual acquisition performance was probably due to the fighter turning toward the target during his "Tally Ho" response. This is evidenced by the fact that this parameter loaded heavily on the fighter velocity factor, while having a negligible loading on the target velocity factor; i.e., the apparent movement of the target across the pilot's field of view was created by the fighter turning toward the target. A further analysis of this parameter suggests that it may be an artifact of the pilot's having first seen the target, began his turn, then reported a "Tally Ho." Interviews with pilots with considerable ACMR experience indicate that this is a possibility.

The relationship between altitude separation and visual acquisition performance was found to be a function of whether the target was above ($r = .576$, $p < .001$) or below ($r = -.159$, $p > .05$) the fighter. This finding is most likely due to the increased target cross section visible to the pilot as altitude separation increases (when the target is above the fighter); when, however, the reverse situation exists, the target becomes obscured by the nose of the F-4 as altitude separation increases.

Another finding in this study that was contrary to initial expectations was the negative relationship between existence of a radar contact and acquisition range; i.e., those engagements in which a radar contact was made resulted in a lower acquisition range than when no contact was made. One would think that the reduced search area resulting form a successful radar contact and subsequent Radar Intercept Officer vectoring assistance would enhance rather than degrade visual acquisition performance of the pilot. That such was not the case may be due to the fact that when the radar is down, there are two pairs of eyes searching for the target. It is also possible that once a radar contact is established, the pilot lowers the priority of a visual acquisition and attends to other aspects of the engagement, confident that he will be able to visually acquire the target. This reasoning is supported by the fact that acquisition rate (percent of opportunities) is greatly enhanced by a radar contact.

It is apparent that any serious attempt to isolate critical pilot skills and abilities responsible for differences in visual acquisition performance on the ACMR must be prefaced by reasonable control over such operational variables as heading of the target, target velocity relative to the fighter's flight path, altitude separation, antenna train angle, target relative position in altitude, and opportunity for radar acquisition by the RIO. To the extent that these known contributors to visual acquisition variance can be controlled, the remaining variation will be due largely to individual differences in pilots. It is the isolation of these differences and the underlying factors responsible for them that will enhance our understanding of in-air visual acquisition performance and allow for the development of selection and training methodologies to improve performance in this vital area.

While it is obvious that the ratio of ACMR output measures to sample size (number of ACM engagements) is low, there was considerable overlap among these measures, as evidenced by the fact that four factors explained 53 percent of the variance of this entire set. The constructs represented by these factors are considerably more resistant to the effects of sampling fluctuations than are individual ACMR measures, and thus more confidence can be placed in the generalizability of the relationships between factor scores and acquisition performance than between individual ACMR measures and performance. This fact does not detract from the main objectives of this investigation since the multiple regression coefficient attained by the four factors and three unique measures exceeded that attained by the original set of significant ACMR output measures.

REFERENCE

1. Hutchins, C. W., and Jones, T. N., An initial investigation of those ACMR parameters related to initial air-to-air visual acquisition. Aerospace Psychology Department Technical Memorandum 75-2. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, August 1975.

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Initial visual acquisition of the adversary aircraft is a critically important task in air combat engagements. In order to assess capabilities for the performance of this task, it is necessary to identify the physical/flight variables which impact this performance.

Measures of 33 flight variables were recorded at the time of initial visual acquisition. Linear regression analysis was utilized to determine the relationship of each

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